RELIABILITY ASSESSMENT AND CALIBRATION OF ISO-LRFD FACTORS FOR MINIMUM FACILITY OFFSHORE PLATFROM IN MALAYSIA

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DEDICATION

Dedicated to my beloved mother Mehrunnisa, respected father Fakhruddin Kamruddin, adorable wife Taslem Bano, my lovely children, Ifrah Momin, Hazik Ahmed, Fatimah Momin and brother Asif Ahmed Momin for their sacrifices and unfailing support

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ABSTRACT

In recent time, the offshore oil and gas industry is facing many challenges like ferocious competition from shale field operators and alternative energy sources, production drop, rising cost etc. All these factors play major role in low crude oil prices. To combat these challenges, the operators are focusing on several untapped field with low production capacity, known as “Marginal Fields” that require innovative design approach to make it economically viable. Minimum facility platform is promising solutions for marginal fields; however, reliability of such structure is a major concern among the operators. In most of the past studies, the reliability technique is effective applied on four (4) legged jacket structure for optimization. This research has attempt to apply reliability analysis method to Mono-tower structure, as minimum facility platform for marginal fields around Malaysia region. The structure was designed as per API RP 2A (WSD). The maximum wave height and current data from Malaysian offshore is using to generate random variables as per Weibull distribution and Monte Carlo Simulation (MCS) have been developed. The surface modelling and curve fitting is done to develop quadrilateral equation in MATLAB for environmental load modelling. Design cases developed as per API RP 2A or ISO19902 must provide adequate levels of reliability throughout the service life. A combination of engineering technique i.e. component based reliability analysis and safety factors, used to ensure integration of all types of uncertainties such as loads, structural properties as resistance, failure modes. FEM method is use for accurate modelling. The probability of failure and reliability index of critical members and other structural members of interest was determined with First Order reliability Method (FORM). The fluctuation in loads and variation material properties were accounted in the assessment. The target reliability level can be achieved either by comparing with existing traditional jacket structure or by following analytical probabilistically models. The partial factors evaluated using reliability assessment is in accordance with concept of Load Resistance Factor Design (LRFD) presented in ISO-19902. Further, the ISO recommendations are followed to calibre the factors as per regional climatic conditions. The estimated reliability Index is 3.95 and probability of failure (Pof) is 5.3x10-5 as per reliability analysis results. Therefore, the conclusion is that Mono-tower as minimum facility platform is suitable for marginal field development that is fulfilling the requirement of reliability, safety and certification. The minimum structure demonstrates equal or higher reliability index for selected members as per ISO. The environmental load calibration has result in factor of 1.26, as against 1.35 suggested by ISO, indicates the potential reduction for Malaysian region without compromising the safety level of structure.

ABSTRAK

Sejak kebelakangan ini industri minyak dan gas luar pesisir menghadapi banyak cabaran termasuklah persaingan sengit dari pengendali-pengendali lapangan syal dan sumber tenaga alternatif, penurunan dalam pengeluaran, peningkatan kos dan lain-lain. Kesemua faktor ini menyumbang kepada harga minyak mentah yang rendah. Bagi menangani cabaran ini, pengendali-pengendali kini sedang menumpukan perhatian kepada beberapa sektor yang belum lagi diterokai dan mempunyai kapasiti pengeluaran yang rendah; ianya juga dikenali sebagai Bidang Marginal (Marginal Fields) dan memerlukan pendekatan reka bentuk yang inovatif untuk menjadikan sektor ini berdaya maju. Platform kemudahan minimum merupakan inovasi yang sangat memberangsangkan untuk bidang marginal; walau bagaimanapun, kebolehpercayaan struktur itu menjadi kebimbangan utama di kalangan pengendali. Kajian-kajian sebelum ini menunjukkan bahawa penggunaan teknik kebolehpercayaan berkesan dalam mengoptimumkan struktur jaket berkaki empat. Penyelidikan ini bertujuan untuk menerapkan kaedah analisis kebolehpercayaan kepada struktur menara 'Mono' sebagai platform kemudahan minimum untuk bidang marginal di rantau Malaysia. Struktur ini direka berdasarkan kepada API RP 2AWSD. Ketinggian maksimum gelombang serta data semasa untuk kawasan luar pesisir Malaysia telah digunakan untuk menjana pemboleh ubah rawak untuk pengedaran Weibull dan menghasilkan Simulasi Monte Carlo (Monte Carlo Simulation. Pemodelan permukaan dan penyesuaian lengkung dijalankan agar dapat mewujudkan persamaan segi empat menggunakan perisian MATLAB untuk tujuan pemodelan beban persekitaran. Kes reka bentuk yang dihasilkan mengikut API RP 2A atau ISO19902 perlu memastikan tahap kebolehpercayaan yang mencukupi sepanjang hayat perkhidmatan. Gabungan teknik-teknik kejuruteraan, iaitu di antara komponen analisis kebolehpercayaan dan faktor keselamatan berasaskan komponen, digunakan untuk memastikan integrasi semua jenis ketidakpastian seperti beban, sifat struktur sebagai rintangan, mod kegagalan. Kaedah FEM digunakan untuk menghasilkan pemodelan yang tepat. Kebarangkalian kegagalan dan indeks kebolehpercayaan anggota kritikal serta elemen struktur penting lain ditentukan menggunakan kaedah kebolehpercayaan First Order (First Order Reliability Method). Keadaan turun naik dalam beban dan variasi sifat bahan juga telah diambil kira dalam penilaian. Tahap kebolehpercayaan sasaran boleh dicapai melalui pembandingan dengan struktur jaket tradisional sedia ada ataupun dengan mengikuti model probabilistik secara analitik. Faktor-faktor separa yang dinilai menggunakan penilaian kebolehpercayaan adalah selaras dengan konsep LRFD dalam ISO-19902. Selanjutnya, ISO mencadangkan untuk menentukur faktor-faktor seperti keadaan iklim serantau. Indeks kebolehpercayaan yang dianggarkan ialah sebanyak 3.95 dan Probability of failure (PoF) adalah 5.3x10-5 berdasarkan hasil analisis kebolehpercayaan. Kesimpulannya, Mono-tower sebagai platform kemudahan minimum sesuai untuk pembangunan dalam bidang marginal dan memenuhi keperluan kebolehpercayaan, keselamatan dan persijilan. Struktur minimum menunjukkan indeks kebolehpercayaan yang sama atau lebih tinggi untuk sesetengah elemen mengikut ISO. Penentukuran beban persekitaran menghasilkan faktor 1.26, berbanding dengan faktor1.35 yang dicadangkan oleh ISO, dan ini menunjukkan potensi untuk pengurangan bagi rantau Malaysia tanpa menjejaskan tahap keselamatan struktur.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
AISC	-	American Institute of Steel Construction
API	-	American Petroleum Industry
BOE	-	Barrel of Equivalent
Capex	-	Capital expenditure
CD	-	Drag Coefficient
CM	-	Mass Coefficient
COSMOS	-	Conductor Supported Offshore Structure
COV	-	Coefficient of Variance
DNV	-	Det Norske Veritas (Norway)
E& I	-	Electrical and Instrumentation
EL	-	Elevation
EOR	-	Enhance Oil Recovery
FORM	-	First Order Reliability Method
GBS	-	Gravity Based Structure
GDP	-	Gross Domestic Production
GoM	-	Gulf of Mexico
HLM	-	Hasfoer and Lind Method
HLV	-	Heavy Lift Vessel
H_{max}	-	Maximum Wave height
H_s	-	Significant wave Height
ISO	-	International Standard Organization
LRFD	-	Load and Resistance Factor Design
MATLAB	-	Matrix Laboratory

MCS	-	Monte Carlo Simulation
MSL	-	Mean Sea Level
MVFOSM	-	Mean Value First Order Second Moment method
NUI	-	Normally Unmanned Installation
Opex	-	Operational Expenditure
PCSB	-	Petronas Carigali Sdn Bhd
PDF	-	Probability Distribution Function
PMO	-	Pennisular Malaysia
PROBAN	-	Probabilistic analysis program
PSC	-	Production Sharing Contract
PTS	-	Petronas Technical Standard
RASOS	-	Reliability Analysis System for Offshore Structures
RSC	-	Risk Sharing Contract
RSR		Reserve Strength ratio
SACS	-	Structural Analysis Computer System
SBO	-	Sabah Operation PETRONAS
SESAM	-	Strength Assessment of Offshore Structure
SIA	-	Structural Inplace Analysis
SKO	-	Sarawak Operation in PETRONAS
SORM	-	Second Order Reliability Method
SRA	-	Structural Reliability Analysis
STRUREL	-	Structural Reliability Analysis software

LIST OF SYMBOLS

β	-	Reliability Index
ϕ	-	Load Factor
μ_Z	-	Mean Value
BS	-	Base Shear
D / ϕ	-	Diameter
E	-	Yong's Modulus
f	-	Safety factors
Fy	-	Yield strength
G1 & G2	-	Permeant Load Action
L	-	Load or Action
LMSM	-	Least Mean Square Method
OTM	-	Overturning Moment
PoF / Pf	-	Probability of Failure
Q1 & Q2	-	Temporary Load Action
R	-	Resistance or capacity
RSM	-	Response Surface Method
S	-	Safety level
T	-	Thickness
Tp	-	Wave period
UC	-	Unity Check (Stress ratio)
V_c	-	Current Velocity
VIV	-	Vortex Induced Vibration
W'	-	Wave Load
WSD	-	Working Stress Design

Xm	-	Model Uncertainty
Z	-	Safety Margin
γ_D	-	Partial Action factor for dead load
γ_L	-	Partial Action factor for live load
γ_W	-	Partial Action factor for Environmental load
σ_Z	-	Standard Deviation

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Petroleum Nasional Berhad (PETRONAS) started operating in 1974 as the Malaysia's National Oil and Gas Company. This was possible with the setting up of the Petroleum Development Act in conjunction with the blossoming oil and gas industry in Malaysia back in the mid 70's. Long before that, oil was only discovered in Sarawak which is located at the eastern part of Malaysia. It was named the Grand Old Lady, which served as an offshore oil production platform in 1900's. In recent days, Malaysian offshores oil and gas activities are operating at Sarawak Operations (SKO) near Sarawak, Sabah Operations (SBO) in Sabah and Peninsular Malaysia Operations (PMO) near Terengganu. Most of the oil and gas activities near Malaysian offshores are managed by Petronas Carigali Sdn. Bhd. (PCSB), in particularly the Exploration and Production (E&P) of Petronas with 200 offshore platforms on operation up to date (Fadly, 2011). These platforms are mostly of the fixed jacket platforms, because it lies at Sunda-Shelf region (South China Sea- shallow water area).

It is an undeniable fact that the contribution of oil and gas industry to the Malaysian economy has been extremely significant over the years. As per the Malaysian oil and gas Industry report, Price Waterhouse Coopers (2016) study reports that "Malaysia's Gross Domestic Production (GDP) in year 2014 upholds gas and condensed crude oil as the highest export material after the electronic and electrical supplies. In addition, this industry also contributes to this country's Gross Domestic Production (GDP) in these years as much as 20%. Along with this, PETRONAS alone profited an overwhelming of RM 881 billion in the form of taxes, royalties, dividends, and duties to the governments within 40 years of its incorporation".

Without doubt, the dropping prices over 60% in the year 2014 and fluctuation within the range USD 35 to USD 45 per barrel in the year 2016 and 2017 with very slow and uncertain recovery in year 2018, implies that the upstream growth force would be difficult or rather questionable. This will cause activities in the domestic upstream which ranges on 6 Risk Sharing Contracts (RSC) and 101 Production Sharing Contracts (PSC) which will put immense pressure on Malaysia's three prolonged approach to unlock reserves:

1.1.1 Marginal Field Development

Malaysia hoped to release an approximate of 600 million Barrel of Equivalent (BOE) spreading them over 100 marginal fields. This approach seems to be facing a lot of challenges, even with a breakeven cost of USD 55 per barrel

1.1.2 Explored Deep Water Fields

Approximately, seven (7) billion of Barrel of Equivalent (BOE) are yet to be discovered resources, with only 50% found by oil and gas organizations up till date, and deep water exploration are obvious facts. However, the delay in this strategy is due to its high cost remuneration which seems reasonable to its current environment situation.

1.1.3 Enhanced Oil Recovery (EOR)

The Enhanced Oil Recovery (EOR) could be carried out onto 14 known oilfields across the country, with its ability to unlock approximately 0.8 to 1.0 Billion of Barrel of Equivalent (BOE) is captivating. Along with the "Monetise Marginal Field" and "Tap under Explored deep water potential" approaches, the possibility to commence with this approach will go through critical observation in this current price environment. This is because 14 billion is needed to execute the first 10 Enhanced Oil Recovery (EOR) projects.

Malaysia is not alone in facing the new challenges, the current geopolitical scenario and volatility in crude oil prices have impacted on offshore field development activities around the world. The projects were delayed and abounded due to low cost benefit ratio. Every passing day, it is becoming more demanding and operators need to look for best practices of doing business as well as consider adopting new technologies, new method of designing, fabricating, installation. The demand for technological advancement as well as emphasis on regional requirement are high. The industry is responding to such demand various ways such as

1. By conducting joint industry Project, workshop and seminars to establish the gap in current standards and develop new standards to serve the industry at large. OGP work shop on OGP Report No. 486, March 2014 (IOGP, 2014) states the Reliability of Offshore Structures - Current Design and Potential Inconsistency is one such attempt to highlight the gaps in various industry standard. The gap in international standard is discussed later in this thesis.
2. Harsh economic challenges faced by the operators and minimal platform designer introducing new concepts caused changes in technology and promoting the use of minimal platforms. Operators and minimal platform designer are working towards simplification on deck, minimize environment impact, design with low visit, sustainable solutions, secondary installation fix, as well as platform automation. For instance, Mustang Engineering and Offshore magazine found 150 operators that has minimal deck designs and 47 engineering companies via “2nd Worldwide Survey of Fixed Minimal Structures”. The knowledge and expertise in developing these marginal field is yet to transfer in Malaysian oil and gas industry.

Currently, the structural designs are solely based on the structural standards including the codes In their documentation a comprehensive methodology is presented that can result in sufficient levels of reliability either as an absolute value of reliability or as an outcome of good practice once the methodology has been followed (Kolios & Bernnan, 2009). This refer to conventional jacket structure having 4-legged or 8-legged structure connected with robust bracing system that was designed as per RP 2AWSD (American Petroleum Institute, 2008). These structures have demonstrated satisfactory performance in term of safety and redundancy. However, such structures are economically not viable for marginal field and hence requires innovative design. (Kolios & Bernnan, 2009) further mentioned that "Designing novel structures, involves the difficulty that no previous experience exists for their design or operation. Therefore, the conditions for design should be determined very thoroughly. Structural standards that refer to specific structures cannot accommodate this scope and therefore a different approach should be considered." The reliability method of designing structure can be promising while it needs to vet for Malaysian environment. Petronas is ambitious to develop capability in design and manage marginal field projects by using innovative approach. The basic requirement for the resulting design should be to build a structure that can perform adequately, able to meet requirements and specifications, based on sound engineering techniques that can be verified and later certified from appropriate certification bodies (Kolios & Bernnan, 2009). It is very important to ensure the safety and the dependability of every offshore structures. These offshore structures have to meet every standard requirement without any fatality and assets loss, at the same time maintaining economic balances.

1.2 Problem Statement

Structural design is an art of managing risk and material cost (Wisch, 1997). The offshore platforms are primarily designed for following three categories of loading.

1. Permanent Action (Dead Load): self-weight of structure, equipment, piping,

2. Variable Action (Live Load): consisting weight of consumables, fluid in equipment & piping, temporary storage of construction and maintenance material and working crew
3. Environmental Action (Environmental Load): This include Waves, Current and Wind

API RP 2A-WSD is set to be the corner stone of all offshore platform design all around the world. This standard design has been proved and accepted since its first issue in the year 1969 (Theophanatos, Cazzulo, Berranger, Ornaghi, & Wittenberg, 1992). In working stress design theory, a factor of safety is applied on material yield strength to reduce the ultimate strength to allowable working strength. A single safety factor is used to cover all kind of uncertainty on material. For the load's factors are generally based on experience. According to (Ayyub, Hill, Shah, Kotwicki, & Gupta, 2007), the usage of deterministic factor of safety with an uncertainty would cause fluctuating reliability which may result in conservative design since WSD does not include individuals uncertainties and real safety margin effects. Overall, this method inherits considerable safety margined which can be optimize and reduce the weight structure suitable for marginal field development.

In 1993, API had published, API Recommended Practice 2A (LRFD), established using Load and Resistance Factor Design method to implement new knowledge gain over the period of offshore engineering practices. However, the same was withdrawing, to merge with ISO 19902 (ISO, 2007). Now ISO 19902 is the latest international standard available for the design of offshore structure. There is drastic difference in the approach of these standards which also create gaps and confusion among users. The approach has been based by the application of variations statistical methods, whereby structures under loading and material geometry strength. A satisfactory safety level for every limit state under consideration can be accomplished when the design capacity is great or equal to design action. The benefit of the reliability technique is to ensure that the structural safety may be defined in a concise manner with different safety factors being applied to the various contributing parameters, each representing differing degrees of uncertainty.

The LRDF code give much emphasis on certain site condition because of the changes from material fabrication and geography. Hence, LFRD method will bring out every variation on the regional differences from the extreme operating conditions of which the designs are referred about ((Nizamani, Kurian, & Liew, 2014)). For offshore structure, it is more relevant due to varying nature of environmental loading which is not distributed normally. The result of load variabilities, effect of the structural reliability is measured by the reliability index (β).

The semi-probabilistic based codes, ISO 19902 (ISO, 2007) and API (LRFD) each have resistance factors and environmental loads that has been based on calibration in Gulf of Mexico and North-Sea. These are the areas of sever environmental condition having natural disasters such as hurricanes (typhoons in Pacific Oceans) as well as severe winter storm respectively. Hence, this particular code is used to design platforms jackets that has lesser severe environment impact such as, South China Sea or more specifically Malaysia or Indonesian region than the design become over-safe and uneconomical. In an estimate, it is presented that by using GoM criterial, the design is amplified by 40-60% due to the lack of data. As a result of this reason, it is entirely important that the actual load factors to be ascertained for this particular region for estimating system reliability. These calibrated factors can be adopted in Petronas Technical Standard (PTS) (2010), to be align the company standard with ISO standards.

1.3 Objectives of the Study

The objectives of this research is performing reliability analysis for Minimal offshore structure suitable for marginal field development. These are the following main objectives for this research:

1. To study the factors affecting reliability index and develop environmental load equation by surface response technique.
2. To evaluate component-based reliability index of Minimum facility platform (Mono-Tower) using Form Method.

3. To compare the reliability index of Minimum facility platform (Mono-Tower) with typical four (4) legged Jacket structure.
4. To calibrate ISO based environmental load factors for Malaysian met-ocean conditions.

The objectives will be achieved by modeling the whole structure using analysis software which will be discussed in detail in Chapter three (3). After which the offshore platform is to be statically analyzed for its stability by only considering the gravity load and environmental load.

1.4 Scope and Limitation of Work

A Mono-Tower structure is selected as minimum facility platform suitable for marginal field development in Malaysian offshore. The structure selection is based on availability of structural data including drawings, foundations i.e. soil data, metocean data from Malaysia region, The structure is assume to be to light weight and new structure designed as per API RP 2A (WSD). The life extension and reassessment is not the intent of this research. The computer based structural modelling has to retain the original design’s geometry with an allowance of changes in design variable and loading. Suction pile foundation is the new concept which can be adopted in Malaysia to further reduce the cost of platform. The data about suction pile foundation was not available in time hence the research proceeded with drilled pile foundation system. Further, this research will focus reliability of Mono-Tower substructure and reliability of pile foundation is excluded. The scope is distributed in three parts for this research project.

First part of scope of work includes study of met-ocean data i.e. 1 year and 100 years wave, current and wind from Malaysian offshore. Develop of environmental parameters using Weibull distribution and generate environmental load equations, for using in reliability analysis. The wave height and current speed is basic parameters in environmental load modelling based on extreme wave parameter.

The second part covers the response of Mono-Tower due to environmental actions. Static In-place structural analysis by applying gravity and environmental loading on structure. The simulation performed in SACS provides base shear, overturning moments and member utilization. The member selection for reliability analysis is as per simulation results from static analysis.

As third part, the scope of work includes carrying out component-based reliability analysis using FORM method. With the help of reliability analysis program developed in MATLAB, estimate reliability index (β), probability of failure (Pof) of critical members and any other member of particular interest. Compare the results with four (4) legged jacket structure reliability index. Evaluate of the effect of environmental loadings variation and finally calibrate the environmental load factors for Malaysian offshore.

This research specifically will not include design condition such as Earthquake, Boat impact and Fatigue. The effect of variation of marine growth and corrosion is not considered. However, corrosion allowances are included as per API RP 2A recommendation for new structures. For simplicity purpose, the dynamic effects are not included at this stage albeit the Minimum facility platform tends to be slender and sensitive to the dynamic effects. These can be included in future as the work progress and time permits. The loadings will be considered as per designed value recommended in American Petroleum Institute (2008) and in platform design premises.

1.5 Computational Tools

In order to conduct linear and non-linear structural analysis, computer models were used by utilizing some of the easily available commercial software such as Structural Analysis and Computing System (SACS). MATLAB and Microsoft Office (Excel), computer based mathematical programming tools are utilized to perform every reliability analyses as well the typical computing tasks for this study. The response surface method has unpredictable models for resistance and load which was created to encompass in this method and has been utilized into the reliability analyses, First Order Reliability Method (FORM) and Monte Carlo Simulation (MCS) is used to determine the reliability index and the probability failure. The analysis approach is component based reliability analysis

1.6 Expected findings

It is expected that this research will apply the theory and methodology of reliability analysis developed based on typical four legged jacket to Mono-Tower offshore structure. The study identified in detail the various level of reliability analysis methods. The factors which influence the reliability index (β) and probability of failure (PoF). It is common perception that the minimal structure tended to be less reliable and weak as compared with four (4) legged jacket structure, hence after performing serval analysis, this study can provide a bases for validating and acceptance of minimal structural concept in Malaysia. The main task is to identify the actual load factors which produce structure with acceptable safety levels that can be classify as "Fit for Purpose". The gravity load and environmental load factors will be studied. It is anticipated that gravity factor will not influence much because of degree of certainty, while environmental factors will plays major role in providing economical design. However, this hypothesis must be verified with multiple structural analysis and mathematical calculations. Following is the summary of expected results after rigorous analysis and research is,

1. Identify the latest development in assessment of reliability of offshore structures. Recommended procedure for reliability analysis.
2. Compute the reliability index and bench mark against four (4) legged jacket structure
3. Validate the ISO LRFD (Nizamani et al., 2014) factors by calibrating environmental factors based on component reliability of Mono-Tower Structure for Malaysian water.

The research intends to run several analyses on Mono-Tower platform by varying the factors to prove the correct structural response under regional geophysical condition. On return, a proper recommendation will be stated based on the results of the analyses and data.

1.7 Layout of Project/Research

The organization of this research is done in order to provide the reader deep overview of the achievement of this study with a very clear and digestive layout. The study will be following after this chapter by another four (4) chapters, where the details of the chapters are as follow:

Chapter one (1) identifies the need for the current research and highlights the objectives to be achieved as well as determines the scope and limitation for this study.

Chapter two (2) will discuss the previous works and literature available on the same topic. Specifically, it will highlight a background of Minimum facility platform structures, environmental loading on offshore structures, background of early works conducted on reliability of offshore structures in various part of the world with specific focus on Malaysian region.

Chapter three (3), on the other hand, will highlight the methodology practiced for the achieving objectives of this study. In chapter three, thorough details will be addressed in determining the concept, the practice of modelling and preparing the model to be analyzed to reach the appointed findings. It will also highlight the methods adopted in creating static In-place analysis model and mathematical modeling for environmental load modeling. Moreover, the source of data will be detailed out and the methods used by software for analysis purposes will be discussed.

Chapter four (4) will shed the light on analysis conducted and the results acquired from the analysis. The important results are summarized in tables and figures and the detail results are attached in the Appendices. This chapter summarizes for all the analysis conducted for this study. A detailed discussion is done in this chapter to further explanation of the concept, as required, with the help of available results.

Chapter Five (5) provides the conclusion for all the results as well as the justification for some concepts. It detailed out listed objectives of this research and provides the recommendations for correct application of reliability theory. The chapter ends with list of suggestions for future research to further develop the concept of Minimal facility offshore platform and advancement of technology

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